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Single-Frequency Operation of a Near-degenerate Optical Parametric Oscillator Using a Transversally Chirped Volume Bragg Grating

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Abstract: We report on single-frequency emission near 2.2 μm with an optical parametric oscillator. The OPO wavelength is tuned over 22 nm using a Bragg reflector incorporating a transverse chirp of the grating period. © 2019 The Author(s)

OCIS codes: (190.4970) Parametric oscillators and amplifiers; (230.1480) Bragg reflectors.

1. Introduction

Spectral selection in an Optical Parametric Oscillator (OPO) behaves very differently than in a laser. It is essentially driven by the phase difference between the generated signal and idler waves and the nonlinear polarization created by the pump. This so-called phase-matching condition writes, in the collinear case: $n_p\sigma_p - n_s\sigma_s - n_i\sigma_i < \Delta\phi_{\max}/2\pi L$, where $n_{p,s,i}$ are the index of refraction at wavenumbers $\sigma_{p,s,i}$, L the crystal length, and $\Delta\phi_{\max}$ is the maximum dephasing allowed by the parametric gain. Derivation of this relation leads to the total first-order gain bandwidth:

$$2\Delta\sigma_s = \frac{1}{\pi L} \frac{\Delta\phi_{\max}}{n_{g,i} - n_{g,s}}, \quad (1)$$

where n_g is the group velocity index. Under pulsed pumping, several longitudinal modes oscillate within the gain bandwidth and, since the oscillation starts from parametric noise, these modes will differ from one pulse to another. This problem is the worst in OPOs using near-degenerate signal and idler waves ($\sigma_s = \sigma_i = \sigma_p/2$) with identical polarizations (type 0 or type I phase-matching), because in this case $n_{g,s} = n_{g,i}$, so that the gain bandwidth becomes very broad. We circumvented this issue by introducing Vernier spectral filtering in doubly-resonant cavities, in which spectral selection is achieved by the coincidence between signal and idler cavity modes [1]. For this scheme to be still effective near degeneracy, we had to resort to periodically-poled lithium niobate (PPLN) with crossed polarizations such that $n_{g,s} \neq n_{g,i}$ (type II phase-matching) [2]. The low non-linear coefficient of PPLN with crossed polarizations was partially balanced by the very low threshold offered by the doubly-resonant cavity.

Recently, Volume Bragg Gratings (VBGs) have emerged as very-narrow, high-efficiency spectral filters for laser applications. They have been used in OPOs to provide narrowband tunable emission [3], and single-frequency operation at a fixed wavelength off degeneracy [4]. In this work, we use a VBG to produce tunable single-frequency radiation very close to degeneracy, while benefiting from the high gain of PPLN with identical polarizations.

2. Design of the transversally chirped Volume Bragg Grating

VBGs fabricated in photo-thermo-refractive (PTR) glass have outstanding properties in the near infrared providing extremely high spectral and angular selectivity with no secondary peak, and diffraction efficiency up to 99.99% [5]. Unlike other holographic materials, PTR glass-based elements have robust performance in harsh environmental condition, unrestricted life time and high laser damage threshold. All above pave the way for their usage as intracavity mode filters in various laser systems.

A transversally chirped volume Bragg grating (TC-BG) is a reflecting VBG in which the transverse period varies across one lateral dimension. Nowadays, state-of-the-art technology allows fabrication of such gratings with lateral dimensions up to 25 mm. For this experiment, we designed a TC-BG which is 20 mm wide, with a chirp rate of 1.1 nm/mm. The FWHM spectral acceptance is 1.2 nm around 2.2 μm and the maximum diffraction efficiency is 80%. The TC-BG is AR-coated at 1.064 μm + 2-2.2 μm . The angular acceptance was checked to be much larger than the mode divergence inside the cavity.

2. Experimental results

The OPO is doubly-resonant with nested signal and idler cavities (Fig. 1, left). The non-linear crystal is a 4.2-mm-long MgO:PPLN crystal with a quasi-phase-matching period of $32.03 \mu\text{m}$ for identical pump, signal, and idler polarizations. The two-pass first-order gain bandwidth given by Eq. 1 is 724 cm^{-1} (spanning 1800 longitudinal modes). The signal cavity is formed by a gold mirror with a 50 mm radius of curvature (M_3) and a highly reflective dielectric mirror deposited on the input crystal facet (M_2). The idler cavity is formed by the gold mirror and the TC-BG which acts as a plane output coupler. The TC-BG is mounted on a transverse translation stage to shift the peak wavelength of the reflectivity curve. The distance between the TC-BG and the signal mirror has been chosen to allow only one signal/idler mode coincidence within the TC-BG bandwidth (Fig.1, right). The TC-BG and the back mirror are mounted on PZT actuators to match the signal and idler combs and finely tune the output wavelength. The oscillation threshold with the TC-BG is $7.5 \mu\text{J}$, identical to the one obtained with a dielectric mirror of the same reflectivity.

Fig. 1. Left: Scheme of the nested-cavity OPO cavity with the TC-BG. Right: Spectral filtering is a combination of signal/idler combs coincidence and selection by the reflectivity of the TC-BG.

Fig. 2 shows the emission spectrum of the OPO when translating the TC-BG, and tuning the PZT actuators to maximize the signal/idler mode overlap. A total tunability of 17 nm was achieved, compliant with the TC-BG specifications. As observed with our previous nested-cavity OPOs, several modes oscillate when the signal and idler combs are mismatched. What is remarkable here is that, despite the huge gain bandwidth, only two neighboring modes are allowed to oscillate, thanks to the high selectivity of the TC-BG. When the signal and idler combs are correctly matched using the PZTs, the OPO emits single-frequency radiation.

Fig. 2. a) Spectrum at different TC-BG positions. Spectrum at one TC-BG position for b) mismatched and c) matched signal/idler combs. The peak width is limited by the spectrometer resolution. The black dashed line is the calculated reflectivity curve of the TC-BG.

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5. References

- [1] B. Hardy, A. Berrou, S. Guilbaud, M. Raybaut, A. Godard and M. Lefebvre, "Compact, single-frequency, doubly resonant optical parametric oscillator pumped in an achromatic phase-adapted double-pass geometry," *Opt. Lett.* **36**, 678-680 (2011)
- [2] M. Raybaut, T. Schmid, A. Godard, A. K. Mohamed, M. Lefebvre, F. Marnas, P. Flamant, A. Bohman, P. Geiser, and P. Kaspersen, "High-energy single-longitudinal mode nearly diffraction-limited optical parametric source with 3 MHz frequency stability for CO₂ DIAL," *Opt. Lett.* **34**, 2069-2071 (2009)
- [3] B. Jacobsson, V. Pasiskevicius, F. Laurell, E. Rotari, V. Smirnov and L. Glebov, "Tunable narrowband optical parametric oscillator using a transversely chirped Bragg grating," *Opt. Lett.* **34**, 449-451 (2009)
- [4] P. Blau, S. Pearl, S. Fastig and R. Lavi, "Single-Mode Operation of a Mid-Infrared Optical Parametric Oscillator Using Volume-Bragg-Grating Cavity Mirrors," *IEEE Journal of Quantum Electronics* **44**, 867-871 (2008)
- [5] O.M.Efimov, L.B.Glebov, L.N.Glebova, K.C.Richardson, and V.I.Smirnov, "High-efficiency Bragg gratings in photothermorefractive glass," *Appl. Opt.* **38**, 619-627 (1999)